URBAN AND RURAL AGRO-FOOD SYSTEMS AS A FACTOR OF LOCAL SUSTAINABLE DEVELOPMENT
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BIOMASS ENERGY PLANTATIONS TOGETHER WITH SLUDGE AND SEWAGE UTILIZATION AS A FACTOR OF SUSTAINABLE RURAL DEVELOPMENT

1. Introduction

EU targets on increasing the share of renewable energy in total energy generation from the present 7% to 12% in 2010 requires an additional annual production of 53 million tons of wood by 2010 (if the present trend is continued only 10 million additional tons will be produced annually). Europe's common agricultural policy [CAP, 2004] is shifting towards development and diversification of economic activities, enabling multiple activities and alternative income. These two goals can be reached by biomass production on short rotation plantations (SRPs). Biomass cultivated in order to generate energy, can be used in a wide variety of biomass conversion products and processes, which fall into four major categories: combustion, gasification, hydrolysis and fermentation, which can produce electricity, heat, combined heat and power and ethanol, respectively [Ciechanowicz, 2003; Szlachta, 2005; Nowicki, 2003]. The economic advantages of using SRPs for energy production are also very important eg. decreased emissions of CO_2 into the atmosphere [Karaczun and Kassenberg, 2001].

Agricultural production of rapidly growing species of tree (the most popular are: willow, poplar, miscant and mallow) can be realized in a wide variety of climate and soil conditions [Stańczyk et al, 2004]. While poplars are commonly cultivated in drier areas, willows were found to be the most suitable crop for regions characterized by a short period of vegetation growth and high level of precipitation [Stolarski, 2004]. The annual yield of biomass produced could be as high as 10–17 Mg of dry matter per ha per year, if optimal soil, moisture conditions are present and appropriate fertilizers used. This could be easily reached by applying wastewater or sludge and using it as a source of nutrients and/or water for biomass production [Dzierżawski and Głażewski, 1995; Lech-Brzyk, 2003; Matys, 2003; Kisiel et al., 2003].

Effluents from wastewater treatment plants (WWTPs) can effectively be used for irrigation by avoiding direct discharge and providing an additional treatment step [Czaja, 2003]. Sludge, as a residue from wastewater treatment, could be used to fertilize SRPs. In areas with limited access to modern treatment facilities, like lowly populated rural regions, SRPs may be a low-cost alternative to the construction of cost intensive, high standard treatment. Treating sludge on SRPs could also raise farmers' income, because of:

– an increase in yield – annual biomass yields could be up to 3 times higher,

– additional income from biological wastewater treatment (nutrient removal). The use of wastewater on SRPs could reduce the costs with respect to conventional nitrogen and phosphorus fertilization. Currently between 7 and 20 Euro is paid per kilo for reducing the the use of nitrogen in fertilizers by using natural fertilizers [Rosenqvist et al, 1997],

– decrease in use and cost of mineral fertilizers.

Currently, willows in particular seem to meet the requirements for efficient treatment/utilization of wastewater by irrigation, because of their fast growth, level of water and nutrient uptake rates and coppice-ability. On the assumption that 15 sqm of SRP is required for wastewater treatment from 1 person (with a daily discharge of 100 liters per person), 10 ha of SRPs would suffice to treat wastewater for 6.500 people during the vegetation period.

Poland, with a vegetation period from 210 days (Gdańsk) to 215 days (Kraków) and annual precipitation of 500 – 700 mm, has favorable conditions for producing willow biomass (about 14 Mg of dry matter per ha annually) [Stolarski, 2004]. To achieve the goal of a 7.5% share of renewable energy in total energy use in Poland by 2010, there is a need to produce 4–5 mln Mg of wood from SRPs. From 2.5 to 2.6 mln ha of agricultural land in Poland could be used for the production of energy biomass [Szlachta, 2005].

The application of wastewater on SRPs has enormous potential in regions where treatment is currently ineffective or unavailable, as in lowly populated rural areas. Taking into account the EU-25 and candidate countries, less than 50% of the population are connected to water and sewage systems. Close to 135 mill. citizens have water supply systems that do not satisfy existing EU standards [EWA, 2003]. In addition, at least half of the existing wastewater treatments plants will have to be modernized to meet legal requirements within 10 years, while decentralized systems will become increasingly important in the European Market [Dohmann, 2002]. SRPs could be an alternative to other biofilters (*e.g.* constructed wetlands), because they combine treatment and production, which provides additional income.

The amount of sludge produced in wastewater treatment is increasing continuously. The dry mass of sludge produced is predicted to double by 2010, as a result of an increase in the number of people connected to wastewater treatment plants [Marciniuk, 2004]. From the beginning of 2005 its disposal in landfill sites will be banned in Europe. In 2002 about 6% of sludge produced in Poland was used in industrial energy production, about 43% of sludge was stored at WWTPs or landfills, 35% for composting, thermal utilization and other processes and only about 15% was used for environmental purposes like soil recultivation, fertilization of agricultural and forest soil and improvement of urban green areas. One potential solution for the growing volume of sludge produced could be the use of sludge for increasing wood biomass growth, in order to generate energy.

On one hand, SRPs represent an economic solution enabling highly efficient biomass production and low-cost wastewater and sludge treatment. On the other hand they could contribute to local independence from external fossil fuels and fluctuations in their prices, to lowering environmental pollution and increasing local employment. The main advantages of wastewater/sludge use on SRPs are:

– effective wastewater treatment (high nutrient uptake and high transpiration rate),
– increase in the rate of biomass production without the use of mineral fertilizers,
– reuse of nutrients by introducing "waste" into the biological cycle,
– decrease in the volume of waste,
– protection of surface waters.

All in all, the potential of SRPs arises from biomass production and wastewater/sludge treatment. This makes the approach a very interesting opportunity for farmers and will further contribute to sustainable rural development.

2. Site description

According to the water framework directive, governments must act so that highly degradated rivers reach the ecological status of "good" by

2015. In some regions technical solutions like building wastewater treatment infrastructure could be insufficient, due to the high concentration of wastewaters in small regions with only a small inflow of water. The Lodz region is an example of such a region. The total amount of wastewater discharged can be as high as 2 m^3 per second, but the natural inflow is 10 times lower. This wastewater – river water ratio is too high to enable reaching a status of "good" without enormous expenditure and use of chemicals and energy in the treatment process. Even if it is possible from a technical point of view, it does not make sense, because in most investment in treatment plants, the process of self-purification of a river is considered as the last step of treatment. This makes it cost-effective and keeps the social costs of treatment acceptably low, which is one of the assumptions of sustainable development. But the Ner river seems to have lost the ability of self-purification. The contaminants which are stored in bed sediments and irrigated valley soil could be slowly released causing internal contamination.

The Ner river is a small, lowland river with a natural flow of 0.2 m^3 per second. The city of Lodz discharges 2 m^3 per second of wastewater and for decades the Ner river was the receiver of such an amount of raw wastewater. Therefore, the average concentration of nitrogen in the river amounted to 23 mgN per L and of phosphorus 11.6 mgP per L (loads: 2898 Mg of N per year and 1462 Mg of P per year respectively). Self purification was mainly carried out by irrigation of grasslands in the valley (about 4500 hectares), which resulted in the removal of more than 1300 tons of nitrogen and about 200 tons of phosphorus.

The valley has specific soil-water conditions with deep sandy alluvial soils and a shallow groundwater table. During the irrigation process the inflow of waste water into an artificially formed dyke infiltrates into the soil and fills the available pores. Any excess of water flows out as surface runoff towards open drainage ditches (Fig. 1). The natural soil-plant system is a dynamic medium for absorbing, treating and utilising the consitituents of wastewater. It works as a mechanical, chemical and biological filter, which is renewed through systematic agricultural use. The research carried out by Matczak [1998] showed that an irrigation system made significant contribution to reducing the level of nutrients and other water pollutants. Reduction of nitrogen in wastewater flowing through irrigated meadow complexes ranged from 33 to 89%, of phosphates – from 23 to 91%, of potassium and BOD respectively: 24–66% and 50–77%. Unfortunately, in some areas, wastewater irrigation also lead to contamination of the soil with hazardous metals. The role of sewage irrigation, however controversial with its side effect of soil contamination, is invaluable for the ecosystem of low lying valleys like the

Warta and Odra valleys. It is the most important factor which reduces the enormous load of contaminants that flow throw the Ner river. We should emphasize that in 1996 the relatively small Ner river was the receiver of 3.5% of total sewage from Poland. Therefore, its impact on pollutant load flowing into the Baltic Sea was great.

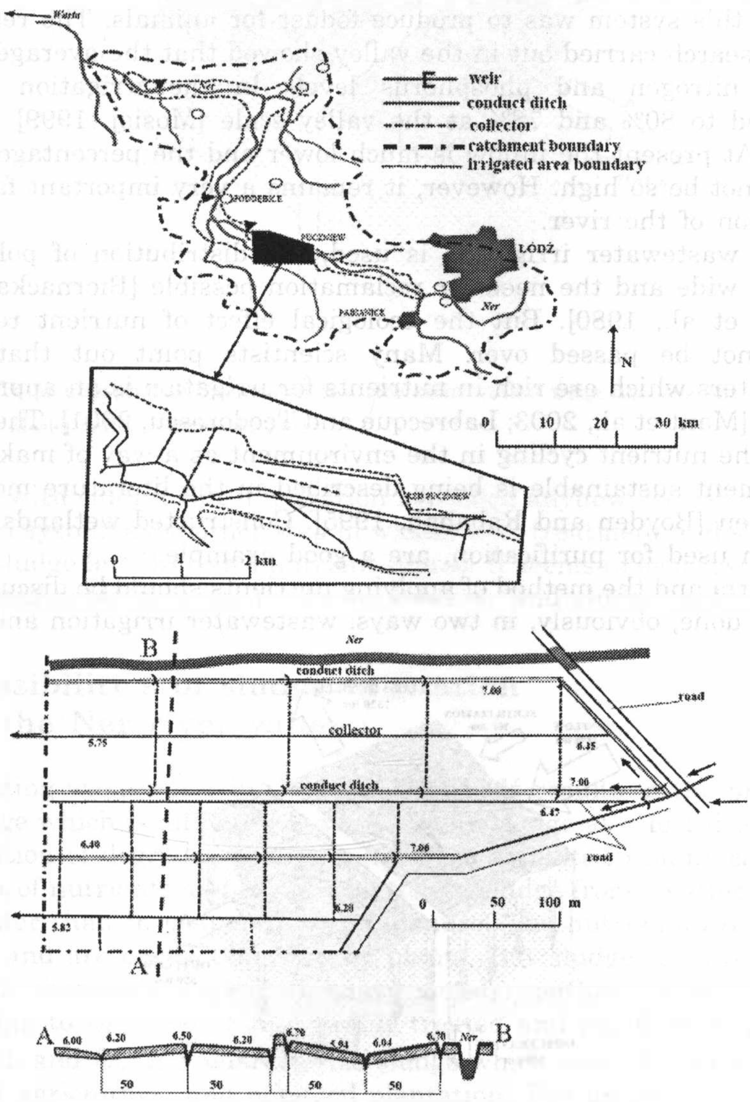

Fig. 1. The drainage catchment of the Ner river, the range and scheme of the irrigation system

Source: Mosiej, 1999.

The treatment plant was started up in the late '90s and water quality, although it was much better, still did not reach a satisfactory level –the level of most chemical pollutants remains high and the water is still classified as category 5 – of the worst quality. The extensive irrigation system existing in the river valley is still used, but because of regress in agriculture production is not so intensive as in the past. The main purposes of this system was to produce fodder for animals. The results of much research carried out in the valley showed that the average reduction of nitrogen and phosphorus levels in the irrigation system amounted to 80% and 78% at the valley scale [Mosiej, 1999] (Fig. 2, Fig. 3). At present the inflow is much lower and the percentage reduction cannot be so high. However, it remains a very important factor in restoration of the river.

When wastewater irrigation is used, the distribution of pollutants could be wide and the need for reclamation possible [Biernacka, 1970; Hemkes et al., 1980]. But the ecological effect of nutrient recycling should not be passed over. Many scientists point out that using wastewaters which are rich in nutrients for irrigation is an appropriate solution [Mant et al., 2003; Labrecque and Teodorescu, 2001]. The role of closing the nutrient cycling in the environment as a way of making the environment sustainable is being described in the literature more and more often [Boyden and Rababah, 1995]. Constructed wetlands, which are often used for purification, are a good example.

The form and the method of applying nutrients should be discussed. It could be done, obviously, in two ways: wastewater irrigation and fertil-

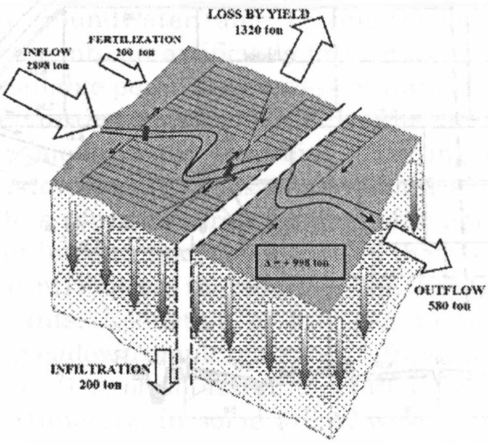

Fig. 2. Total nitrogen balance in the Ner river valley irrigation system

Source: Mosiej et al., 2002.

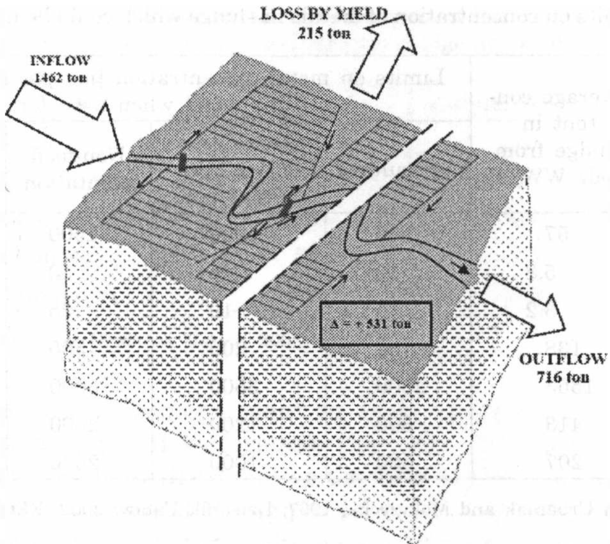

Fig. 3. Total phosphorus balance in the Ner river valley irrigation system
Source: Mosiej and Kaczmarczyk, 2001.

ization with sludge. But if irrigation is needed anyhow, we can use an irrigation system as another step in wastewater treatment and separately apply sludge fertilizer as a nutrient source. It seems to be a cost-effective and sustainable solution to the wastewater and sludge problem.

3. Possibilities of sludge utilization in the Ner river valley

Treating wastewater in the WWTP in Łódź results in the production of sludge which is difficult to utilize. Using sludge as a fertilizer and for restoration of degraded soil gives very good results in many cases. The content of nutrients and organic matter in sludge from treatment plants is greater than in commonly used manure. The nutrients are released slowly and are easily taken up by plants. But sludge can also contain harmful chemicals (especially heavy metals), pathogens and parasites according to the type of wastewater treated and purification process.

Polish and EU law characterize sludge which could be used as fertilizer for agricultural and non-food plantation. The limits on the concentration of hazardous metals are shown in Table 1.

As shown in the table, the sludge from the Łódź WWTP meets all of the conditions used for non-food plantations and for restoration as well.

Table 1. The limits on concentration of metals in sludge which could be used as fertilizer

Metal	Average content in sludge from Łódź WWTP	Limits on metal concentration [mg per kg dry weight of sludge] when used for:			
		Agriculture	Restoration of non-agriculture land	Non-food plantation	EU Directive 1986/276/EEC
Lead	57	500	1000	1500	750–1200
Cadmium	5.8	10	25	50	20–40
Mercury	3.2	5	10	25	16–25
Nickel	138	100	200	500	300–400
Zinc	1553	2500	3500	5000	2500–4000
Copper	413	800	1200	2000	1000–1750
Chromium	207	500	1000	2500	—

Source: based on Urbaniak and Mokrzycka, 1997; Dziennik Ustaw, 2002; EEC/1986/278.

But in this case, one critical factor is also the concentration of metals in the soil. This limitation, according to the research of Liwski et al. [1990], could be the main obstacle to sludge utilization in these way, especially in most contaminated profiles located near the WWTP.

Polish law also specifies the amount of sludge that can be applied as fertilizer. The law allows the first application to be as high as 250 Mg d.w. per hectare and this level can be applied during the first 3 years. In subsequent years the amount of sludge used is limited to 10 Mg per hectare.

The main advantage of using sludge as fertilizer is lower costs of fertilizing costs or even obtaining revenue, as treatment plants pay sludge receivers (*e.g.* farmers) from 30 to 100 PLN per Mg of dry weight for sludge utilization.

The Willow *Salix viminalis* is one of several plants used for energy plantations and wastewater treatment [Hasselgren, 1998]. It seems to be the best plant for the case studied. The plant's demand for water is high, so it could be cultivated on irrigated parts of the Ner valley, even if it is contaminated by heavy metals [Pulfold and Watson, 2003]. As a non-food crop, it could also be fertilized with sludge contaminated by heavy metals. To get 20 tons of dry willow biomass per hectare, about 150 kg of nitrogen, 18 kg of phosphates and 60 kg of potassium [Pertu, 1993] are needed. Therefore, we should estimate the content of available nutrients in the soil, sludge and irrigation water. However, one goal of this plantation might just be sludge and sewage utilization, together with heavy metals phytoremediation, not just biomass production.

Table 2. The limits on the concentration of hazardous metals in soil which can be fertilized with sludge [mg/kg d.w.]

Metal	Light soil	Medium-heavy soil
Lead	50	75
Cadmium	3	4
Zinc	150	220
Copper	50	75
Chromium	100	150

Source: Dziennik Ustaw, 2002.

The wastewater treatment plant in Łódź produces about 35 Mg dry weight of sludge daily. If we assume that over 20 years of using willow plantations for sludge utilization, we use 250 Mg/ha for land reclamation during the first 3 years and 10 Mg per ha in subsequent years, we can utilize a total amount of 420 Mg of sludge per hectare. This results in an average of 21 Mg per ha per year on average. To utilize all the sludge produced at the WWTP we need about 650 hectares of willow plantations. Using only 10 Mg/ha per year as permitted after the initial three year period, the area needed for sludge utilization would be about 1300 hectares. Both scenarios are possible to implement, because the area in which willow plantations could be set up is estimated to be 4000 hectares.

4. Conclusions

1. The irrigation system in the Ner river valley has been the most important factor in reducing the river pollution for decades. A huge proportion of nutrients was removed before it reached the river body, but on the other hand the large concentration of contaminants left in the soil makes it useless for food plantation. In the age of the Water Framework Directive and the new standards of environmental protection changes in land use are needed, but the irrigation system should be still used. It must be included in a new vision of river basin management.

2. The main changes should be applied to the structure of plant and agricultural production in the valley. Energy plantations should be established on the area contaminated by metals and parts of the area which meet requirements could be used as energy plantations fertilized by sludge. This could solve the problem of managing sludge from WWTP. Additionally, irrigation with water from the Ner river will improve the quality of the water and increase the moisture in the soil, which is necessary for growing willows.

3. Selection of the areas for sludge utilisation should be proceeded by an analysis of the concentration of heavy metals in the soil. In areas where these limits are exceeded (industrial areas according to classification) recultivation is needed. Such areas occur sporadically in the Ner river valley, in small plots, mainly in local depressions where wastewater sediments have accumulated during repeated winter irrigation.

4. Before qualifying an area for energy plantation and sludge fertilization, it is necessary to determine the condition of the soil. Areas in which the limits on the concentration of hazardous metals in the soil are exceeded could be used for energy plantations, but without sludge fertilization. In this case nutrients should be provided by irrigation only. The concentration of willow plantations in a relatively small area will result in establishing an industrial infrastructure for the processing of willow biomass and its distribution and make it a much more cost-effective way to provide renewable energy in this region.

5. SRPs represent an economic solution for highly efficient biomass production and low-cost wastewater and sludge treatment. On the other hand they can contribute to local independence from external fossil fuels and fluctuation in their prices, to lowering environmental pollution and increasing local employment.

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